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Gamma rays from the 7.6 Mev state of O^{15}

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With 7 figures in the text

ABSTRACT

The gamma rays from the 7.55 Mev state of O^{15}, produced by proton bombardment of N^{14}, have been studied with a scintillation spectrometer. The three modes of de-excitation through intermediate levels have been confirmed by coincidence measurements. The energy values obtained for these levels are 5.16 ± 0.04, 6.15 ± 0.03 and 6.77 ± 0.02 Mev. No asymmetry of the photopeak of the 2.39 Mev gamma ray, indicating a splitting of the 5.16 Mev level, could be observed.

1. Introduction

In the bombardment of N^{14} by protons with an energy of 277 kev, O^{15} is produced in an excited state. The nucleus is de-excited by the emission of gamma rays, and then it decays into N^{15} by positron emission. The reaction has been studied by measurements of the gamma rays [1–4] and of the positrons [5, 3]. The nucleus produced at the proton capture is excited to 7.55 Mev. Direct decays to the ground state have not been observed. The de-excitation takes place in two steps through one or other of three levels between the 7.55 Mev level and the ground state. These levels have an energy of 5.27, 6.14 and 6.82 Mev according to Ajzenberg and Lauritsen (6).

Earlier measurements of the gamma rays have been made with rather small scintillation crystals. Since the yield of the reaction is very low, 2.7×10^{-11} gamma per proton on thick nitrogen, the counting rate of the detector is then rather low. Therefore, no measurements are published where the gamma rays are studied by coincidence measurements. The use of big crystals would increase the counting rate, thereby making possible coincidence measurements to confirm the cascade transitions. Besides, the measurement of the gamma ray energies can be made in a shorter time, with hopes of a higher accuracy.

2. Experimental arrangement

As a source of protons, the van de Graaff generator of the Department of Physics, University of Lund, was used. In order that the machine should work well at voltages below 300 kV, two thirds of it were short-circuited. Proton currents between 30 and 50 μA were used. Under these circumstances, the voltage stability was 2 %, which was enough for this purpose. The energy was controlled by 20° magnetic deflection. The targets used were thin layers of urea, being rather rich in nitrogen. The urea

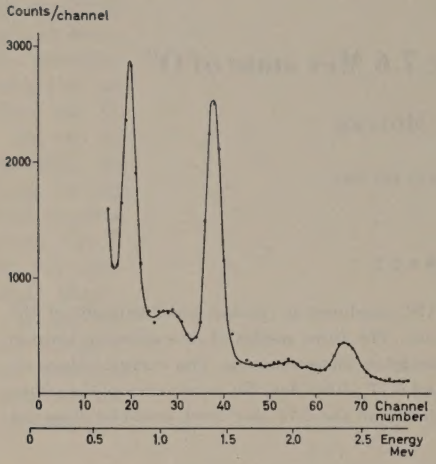

Fig. 1. Scintillation spectrum of gamma radiation below 3 Mev from the 277 kev resonance of $N^{14}(p,\gamma)O^{15}$. The peaks originate from gamma rays with energies of 0.78, 1.40 and 2.4 Mev.

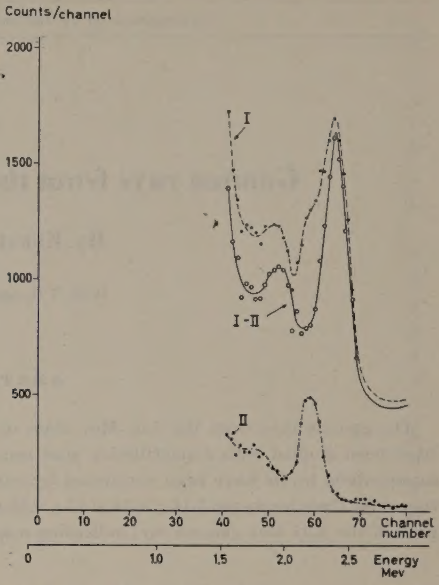

Fig. 2. Scintillation spectrum of the 2.39 Mev gamma ray of O^{15}. Curve I is the pulse height distribution with a proton energy of 285 kev, curve II is the background recorded with a proton energy of 269 kev, and the curve between the two is the resulting spectrum.

was evaporated on copper. The targets were thick compared to the width of the resonance (< 2 kev), but so thin, that no considerable decomposition took place.

The gamma rays were detected by two NaI(Tl) crystals, 5″ diameter, 4″ long, mounted on type 6364 DuMont photomultiplier tubes. The crystals were placed at 90° from the proton beam, 5 cm from the target. No collimation was used. The crystals were screened off from the surroundings by 12 cm of lead. The pulses from one of the photocells were analysed by a 100-channel pulse-height analyser of the Hutchinson–Scarrot type. The pulses from the other photomultiplier were used in the coincidence measurements.

3. Measurements with single-crystal spectrometer

The energies of the gamma rays are, according to [6], 0.79, 1.47, 2.34, 5.27, 6.14 and 6.82 Mev. The measuring of the first three of these is most convenient, and from these the three higher energies can be calculated. The proton energy was 8 kev above the resonance energy. The current through the deflecting magnet was used for energy measurement, and the energy calibration was done by measuring the yield curve of the reaction, since the resonance energy is known to be 277 kev. The scintillation spectrum of the range up to 3 Mev is shown in Fig. 1. The background, which has been subtracted, was measured with the proton energy decreased to 8 kev below

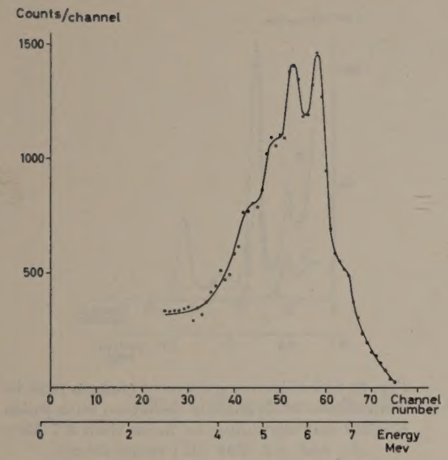

Fig. 3. Scintillation spectrum of the high energy gamma radiation from the 277 kev resonance of $N^{14}(p,\gamma(O^{15}$. Three gamma rays, each giving a pulse height distribution with two peaks, are mixed. The energies of the gamma rays are 5.2, 6.2 and 6.8 Mev.

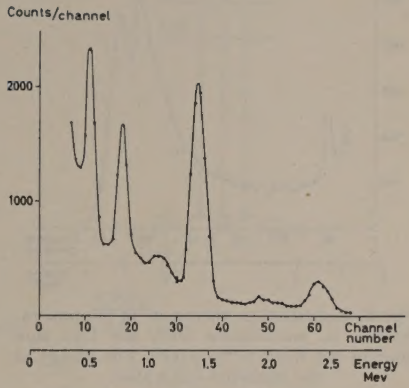

Fig. 4. Scintillation spectrum for gamma rays with energies below 3 Mev in coincidence with gamma rays with energies above 3 Mev from the reaction $N^{14}(p,\gamma)O^{15}$.

the resonance. The energy scale was calibrated with Na^{22}. The two lowest energy values obtained are 0.78 and 1.40 Mev. The small peak around 1.05 Mev is the Compton distribution peak from the 1.40 Mev gamma ray. Its size depends on the geometry and has its correspondence in the spectrum of the 1.28 Mev line from a Na^{22} preparate at the place of the target.

The peak at 2.4 Mev has been particularly studied, Fig. 2. The upper curve, I, is the pulse height distribution with a proton energy of 285 kev; the lower, II, is the background spectrum with a proton energy of 269 kev, and the curve between I and II is the difference between them, and thus the wanted spectrum. The peak at 2.2 Mev in the curve II comes from the reaction $C^{12}(p,\gamma)N^{13}$, the resonance energy of which is 457 kev, giving a maximum gamma energy of 2.19 Mev at the proton energy used. The carbon is mainly present as a thin surface layer through the decomposition of the urea. From Fig. 2 the energy value 2.39 Mev is obtained for the gamma ray from O^{15}. It would have been of great interest if this line could be shown to consist of two components, since this would have meant a splitting of the 5.2 Mev level of O^{15}, analogously to the lowest level of N^{15}. The resolution, however, is not good enough to allow any conclusions in this respect. In N^{15} the splitting is 30 kev, and in O^{15} it may be still smaller.

From these measurements, the following values are obtained for the excited levels in O^{15}: 5.16 ± 0.04, 6.15 ± 0.03 and 6.77 ± 0.02 Mev.

These energy levels may also be observed directly with the scintillation spectrometer as is shown in Fig. 3. With the geometry used, a gamma ray with an energy of about 6 Mev gives one total-capture peak and one 10 % higher single-escape peak, while the double-escape peak is almost undetectable (see Fig. 5). The spectrum is a mixture of three such distributions with the relative proportions 25, 100 and 40

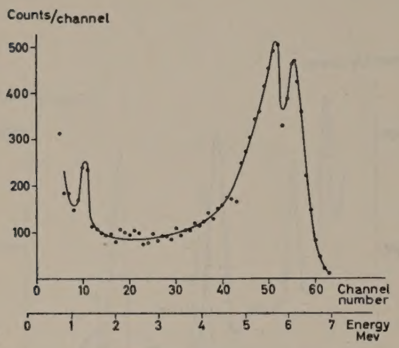

Fig. 5. Scintillation spectrum of gamma radiation in coincidence with the 1.40 Mev gamma ray from $N^{14}(p,\gamma)O^{15}$. The energy of the radiation is 6.2 Mev.

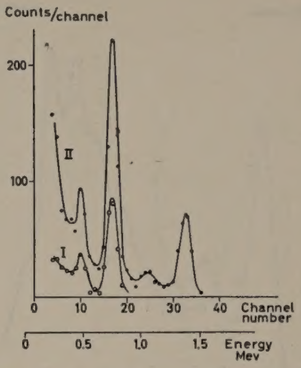

Fig. 6. Scintillation spectra of gamma rays in coincidence with gamma radiation with pulse heights corresponding to more than 6.7 Mev (I) and 6.2 Mev (II) respectively.

for the energies 5.16, 6.15 and 6.77 Mev respectively [3]. Six peaks should appear, but the single-escape peak from the 6.77 Mev line adds to the total-capture peak of the 6.15 Mev line, reducing the number of peaks to 5. The energy values, obtained from this curve, agree with the calculated values above, but of course they cannot be measured with the same accuracy.

4. Coincidence measurements

The level scheme has been controlled by coincidence measurements. For this purpose, two coincidence circuits, one single-channel analyser and one 100-channel analyser have been used. The first coincidence circuit, having a resolution time of 0.3 μs, has worked directly on the pulses from the photomultipliers. The output pulses from this circuit are fed to one input of the second coincidence circuit (resolution time 1 μs): the other input is fed by the output pulses from the single-channel analyser, by which a suitable energy interval is selected from the pulses from crystal No. 2. The output pulses from the slow coincidence circuit open the gate of the 100-channel analyser. Thus pulses from crystal No. 1, which coincide with the selected pulses from crystal No. 2, are analysed.

Fig. 4 shows gamma radiation up to 3 Mev in coincidence with gamma rays with energies higher than 3 Mev. Besides the 0.78, 1.40 and 2.39 Mev lines, there is a line at 0.51 Mev, which is the annihilation radiation from positrons, produced in the target and the surroundings.

The transition from the 7.55 Mev state to the 6.15 Mev level and then to the ground state has been controlled by studying the gamma radiation in coincidence with the 1.40 Mev line. With the single-channel analyser, the interval 1.25–1.60 Mev was selected, which encloses the photo-peak of this line. Fig. 5 shows the result. The energy of the gamma ray is 6.2 Mev, and the shape of the spectrum corresponds to the 6.14 Mev line from proton bombardment of fluorine with this geometry. Because of the method of measurement, some of the low energy radiation will also appear in this spectrum.

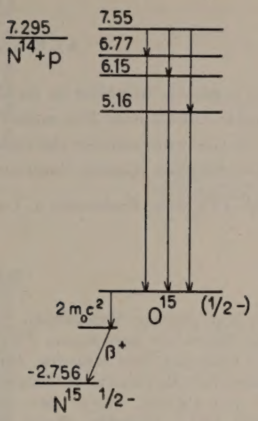

Fig. 7. Energy level diagram of O^{15}.

From a comparison between Fig. 5 and Fig. 3 it appears that pulses with heights corresponding to more than 6.7 Mev should come only from the 6.77 Mev radiation. The energy of the coincident radiation should then be 0.78 Mev. This is evident in Fig. 6, curve I. If instead all pulses with heights corresponding to more than 6.2 Mev is selected, radiation coinciding with the 6.15 Mev line will also appear. This is shown in curve II of Fig. 6. These measurements confirm the deexcitation in the cascades 0.78–6.77, 1.40–6.15 and 2.39–5.16 Mev.

5. Discussion

In earlier papers on gamma rays from O^{15}, the level excited at this proton energy is assigned an energy of 7.61 Mev. This value is based on the maximum positron energy and the masses of N^{14}, N^{15} and H^1. However, the accepted value of the positron energy seems to have been about 50 kev too low. Measurements of the (p,n) threshold of N^{15} [8, 9] and new spectrometer measurements [10] give a $Q = 2.756$ Mev for the decay of O^{15} into N^{15}, instead of the earlier value 2.705 Mev. By use of the new Q value and the mass excesses 7.001, 4.534 and 7.584 for N^{14}, N^{15} and H^1 [11], the Q_m of N^{14} (p, γ) O^{15} will be 7.295 Mev, and the level excited by 277 kev protons will have an energy of 7.55 Mev. This value has been used above.

Earlier measurements of comparable accuracy of the levels studied here have given the following results: Johnson, Robinson and Moak [2], 5.29 ± 0.10, 6.21 ± 0.10, 6.84 ± 0.10; Bashkin, Carlson and Nelson [3], 5.25 ± 0.1, 6.10 ± 0.1, 6.65 ± 0.15; Bent *et al.* [4], for the two highest levels, 6.12 ± 0.06 and 6.81 ± 0.04. The values obtained here are 5.16 ± 0.04, 6.15 ± 0.03 and 6.77 ± 0.02 Mev. The errors stated are estimated from repeated measurements and from observations of the drift of the energy calibration.

The energy level diagram, Fig. 7, has not been provided with spin assignments because of the uncertainty of the spin of the 7.55 Mev level. The results of measurements by Bashkin *et al.* [3] is $J = 5/2$ and by Overley *et al.* [7] $J = 1/2$. It would be of interest to make a new measurement of the angular distributions of the gamma rays to get rid of this ambiguity.

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